THE SIMPLE METHOD OF SELECTING PARENTAL LINES TO PRODUCE SYNTHETIC VARIETIES OF HIGH YIELD IN MAIZE, *ZEA MAYS* L.

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Received March 9, 1972

Introduction

The term "synthetic variety" has been used to designate the advanced generations of multiples hybrid increased by open-pollination. HAYES (1926), KIESSEBACH (1933), and SPAGUE and JENKINS (1943) have reported that synthetic variety was rather similar to an open-pollinated variety, and synthetic variety recently was designated by LONNQUIST (1961) as "an open-pollinated population derived from the intercrossing of selfed plants or lines and subsequently maintained by routine mass selection procedures from isolated planting".

The main objectives in development of synthetic variety have been to increase the gene frequency for the specific attributes as well as to assemble as many desirable productive genes as possible in order to obtain and retain heterosis throughout several generations. Therefore, the term of synthetic variety is used restrictly by some of maize breeders, to combinations involving more than 4 parents.

In synthetic variety of maize, the maximum heterosis will be obtained in the first generation. In later generations there may be a reduction in vigour brought about by the intercrossing between the related individuals and by the random self-fertilization. The amounts of intercrossing and random-selfing are quite depent on the number of unrelated plants or lines upon which the synthetic variety is based. The most important factor which affects directly on vigour of successive generations in a synthetic variety of maize is the optimum number of parents, whereby.

WRIGHT (1922) developed a method of expanding path coefficeints and presented a formula for computing the predicted yield of F_2 generation based on the assumption of arithmetric gene action. The formula has been applied by NEAL (1935), KINMAN and SPRAGUE (1945) to compare the theoritical yield of maize synthetic varieties based on 2 to 10 inbred lines.

Recently, THAD (1966) reported that the rate of change in inbreeding in synthetic varieties per generation, is always greater than 1/2, for diploid, equilibrium is reached in one step past SYN 1, i. e., in the SYN 2, involved from 2 to 64 parents. In order to evaluate a synthetic variety we need to predict the yield performance of SYN 2.

In this paper, the authors prefer to introduce the very simple method of computing the number of inbred lines, which should be used to produce a synthetic variety of high yield by expanding the GARDNER and EBERHART's genetic model.

GENERAL MODELS:

GARDNER and EBERHART (1969) presented a model for the estimation of genetic effects from diallel cross and related population of a fixed set of random-mating varieties with an arbitrary gene frequencies at all loci assuming diploid inheritance, two alleles per locus and no epistasis.

The mean performance of any variety (V_k) and any variety selfed (V_k^s) can be expressed simply as follows:

$$V_k = V_{kk} = \mu + a_k + d_k \qquad \text{(I)},$$

and

$$V_k^s = V_{kk}^s = \mu + a_k + 1/2 d_k \qquad \text{(II)}.$$

In this terminology μ is the mean of random inbred lines from all varieties, thus $\mu + a_k$ can be understood as the mean of random inbred lines from the k^{th} variety, and $\mu + a_k + d_k$ is the mean of the k^{th} variety. The a_k and d_k represent the contributions of homozygous loci and heterozygous loci, respectively to the k^{th} variety mean. The mean expectation of variety cross ($C_{kk'}$) will be as follows:

$$C_{kk'} = \mu + 1/2(a_k + a_k) + 1/2(d_k + d_{k'}) + h_{kk'},$$

where h_{kk} is the heterosis parameter (positive and negative) which is due to the difference in genes by which V_k and $V_{k'}$ differ to dominance.

The formula (I) and (II) have been used directly by MOCHIZUKI (1970) to develop the theoritical method of predicting the F_2 of synthetic varieties of maize. Actually, it is quite difficult to project an experimental plan of breeding synthetic varieties just fitted for investigating the value of $\mu = 1/n \sum_{k=1}^{n} (\mu + a_k)$, and if selfed plants of parental varieties are not planted isolotely, it will be impossible to compute separately the gene effects of a_k and d_k.

Furthermore, from the formulas of (I) and (II), we know that V_k^s is produced by selfing a representative somple of plants in V_k, V_k only differs from V_k^s by $\frac{1}{2}d_k$, and, as $d_k=0$ for pure line varieties or inbred lines, $V_k=V_k^s$ for these special cases.

Then, the synthetic varieties of maize are derived from parents as inbred lines, and the mean expectation of the k^{th} line can be written in the other model as follows:

$$L_k = \mu + a_k + e_k \qquad (k = 1,\ 2,\ 3,\ \cdots\ n)$$

Where μ is the average mean of all inbred lines used in the experiment, and e is a component resulted by the response of gene to environment or the genotype-environment interaction; e can be positive and negative and, then $\sum e_k=0$

Let put

$l_k=a_k+e$ as a line effect in the experiment ant it can be estimated by (the phenotypic value of the k^{th} line-the average mean of all lines).

C_{kk} is the mean of F_1 and $C_{kk'}^s$, $C_{kk'}^r$ are the means of selfed and random mating generations from the inbred line crosses, respectively. The expectations for the entries are as follows:

$$C_{kk'} = \mu + \tfrac{1}{2}(l_k + l_{k'}) + h_{kk'}$$
$$C_{kk'}^s = \mu + \tfrac{1}{2}(l_k + l_{k'}) + \tfrac{1}{2}h_{kk'}$$
$$C_{kk'}^r = \mu + \tfrac{1}{2}(l_k + l_{k'}) + \tfrac{1}{2}h_{kk'}$$

When four or more lines are used to produce the diallel cross and related populations, the parameter $h_{kk'}$ can be partitioned to provide additional informations as follows:

$$h_{kk'} = \bar{h} + h_k + h_{k'} + s_{kk'}\,,$$

where $\bar{h}$ is the average heterosis contributed by the particular set of lines used in crosses; h_k is the average heterosis contributed by line k in its crosses measured as a deviation from average heterosis ($\sum h_k=0$) and $s_{kk'}$ is the specific heterosis that occurs when line k is mated to line k'. The restriction $\sum_k s_{kk'}=\sum_{k'} s_{kk'}=0$ is required.

Now let us consider a synthetic variety being produced by random mating from 3, 4, 5, $\cdots$ n parental inbred lines. The parent used are called the SYN. 0 and their offsprings $C_{1.2.\cdots n}$; $C_{1.2.\cdots n}^r$ are the SYN. 1 and the SYN. 2, collectively (the detail proccess of expanding the formula can be seen in MOCHIZUKI 1970 or HO 1971).

The means of SYN. 1 and SYN. 2 are as follows:

$$C_{1.2.\cdots n} = \mu + 1/n\,(l_1 + l_2 + \cdots + l_n) + \frac{n}{n(n-1)}(h_{1.2} + h_{1.3} + \cdots + h_{n-1.n}) \qquad \text{(III)}$$

and

$$C^{r}_{1.2.\cdots n} = \mu + 1/n\,(l_1 + l_2 + \cdots + l_n) + \frac{2}{n^2}(h_{1.2} + h_{1.3} + \cdots + h_{n-1.n}) \qquad \text{(IV)}$$

Clearly, we can predict easily the yield performance of SYN. 2 by formula (IV) after taking the deviations $l_k\,(k=1, 2, 3, \cdots n)$ and computing the values of $h_{kk'}$.

RELATION WITH WRIGHT'S FORMULA

Now we go back to the general model where $h_{kk'}$ is designated as heterosis parameters.

$$h_{kk'} = C_{kk'} - \tfrac{1}{2}(L_k + L_{k'}), \text{ and therefore}$$
$$h_{1.2} = C_{1.2} - \tfrac{1}{2}(L_1 + L_2)$$
$$h_{1.3} = C_{1.3} - \tfrac{1}{2}(L_1 + L_3)$$
$$\cdots\cdots\cdots\cdots\cdots\cdots$$
$$\cdots\cdots\cdots\cdots\cdots\cdots$$
$$h_{n-1.n} = C_{n-1.n} - \tfrac{1}{2}(L_{n-1} + L_n)$$

By substituting $h_{kk'}$ in the formula (IV) by $C_{kk'}$, L_k, and $L_{k'}$. We have the following mean performance of the SYN. 2 population,

$$C^{r}_{1.2.\cdots n} = C_{1.2.\cdots n} - 1/n\left[C_{1.2.\cdots n} - 1/n\,(L_1 + L_2 + \cdots + L_{n-1} + L_n)\right] \qquad \text{(V)},$$

where

$$\bar{C}_{kk'} = \frac{2}{n(n-1)}\sum_{\substack{kk' \\ k<k'}}^{n} C_{kk'} = \frac{2}{n(n-1)}(C_{1.2} + C_{1.3} + \cdots + C_{n-1.n}) = C_{1.2\cdots n}$$

$$\bar{L}_k = 1/n\sum_{k=1}^{n} L_k = 1/n\,(L_1 + L_2 + \cdots + L_n)$$

Therefore, the mean of SYN. 2 population (V) can be written in an other form as follows:

$$C^{r}_{1.2.\cdots n} = \bar{C}_{kk'} - 1/n\,(\bar{C}_{kk'} - \bar{L}_k) \qquad \text{(VI)}$$

This shows that the above formula is the same with the one presented by SEWALL WRIGHT (1922) for calculating the predicted yield performance *of F_2 generation of synthetic variety and its succeeding generations,* respectively as follows:

$$F_2 = F_1 - (F_1 - P)/N,$$

where

F_2 = yield of synthetic in advanced generation

F_1 = yield of synthetic in the first generation

P = average yield of inbred component lines

N = number of lines

Discussion

As we have said in the introduction, there occur the intercrossing between the related plants and the random self-fertilisation from the F_2 generation of synthetic varieties. Theoretically, it invites the depression of gene effects to a half, such as 1/2 d in V_k^s and 1/2 $h_{kk'}$ in $C_{kk'}^s$. Then, for any number of n parents, the second generation never reached that of the first generation. If too few in SYN. 0 are used, the vigour in SYN. 2 and subsequent generations will be greatly reduced. On the other hand, too many are used, the synthetic variety is likely to be more heterogeneous in specific characters other than vigour and less stable during seed increase, and undesirable reduction per generation in yield will be resulted.

KINMAN and SPRAGUE (1945) made further studies of synthetic varieties, comparing the theoretical yields of maize synthetic varieties derived from 2 to 10 inbred lines. The data indicated that with the materials used comprizing 5 or 6 lines were the most sufficient. Theoretically, MOCHIZUKI (1969) reported that the optimum number of parental varieties variated from 5 to 8 according to the homozygous degree of the materials. The authors also studied with the parental inbred lines originated from same origin, and obtained the results that it is not neccessary to use so much parents, since their genotypes are nearly the same or bearing genes acting at the same level, and extremly, 3 inbred lines seemed to be suitable. On the other hand, if diversely originated inbred lines are used, the optimum number of parents became larger than the above case, i. e., the number of parents should be used increasing with the range of divergene of parents in genotype.

It is readily apparent from the formula (IV) given above that the yield of advanced generations of a synthetic variety of maize is dependent upon four factors:

(1) the number of parental lines involved, (2) their mean performance

$\bar{L}_k$ or $1/n \sum_{k=1}^{n} L_k$ as lines, (3) the mean performance of all possible combinations among lines. The fourth factor, which can be largely disregarded in maize, is the amount of self-fertilization because of the frequency of random self-fertilization or selfing is $1/n$. The fraction $1/n$ is of significant in SYN. 0, but in advanced generations, (n) becomes larger and larger and the fraction $1/n$ is very small, being of non-significant. The factor (2) and (3) show that a relatively desirable synthetic variety is only derived from inbred lines which nust be the high mean performance in yield per se. and per crosses among these lines.

NUMERICAL EXAMPLE

Data of yield performance of 10 inbred lines and their 45 crosses in diallel set without reciprocals, is taken out from the experiment in 1970. The measurements consist of ear weight and shelled corn yield (kg per arre).

As can be seen from the estimates of Table 2 and data given in

Table 1. Yield of 10 inbred lines and their 45 crosses (kg/a).

N 28	N 56	N 146	N 203	N 206	T 6	T 23	T 113	T 24	T 117	
20.93 17.34	60.90	67.80	64.94	69.31	68.51	63.70	60.23	56.61	51.06	N 28
52.51	36.75 30.70	66.29	51.43	70.12	62.84	71.66	55.19	63.68	53.76	N 56
49.33	55.75	28.37 22.88	65.68	70.36	73.75	64.81	69.30	64.69	56.44	N 146
55.16	42.43	05.14	29.48 22.20	72.89	75.29	73.38	64.50	76.65	59.45	N 203
60.13	62.65	60.13	60.62	23.70 18.24	72.21	81.28	78.13	76.96	59.63	N 206
59.09	64.20	63.52	55.19	62.22	10.87 8.56	52.36	56.61	65.25	52.66	T 6
55.25	62.50	55.44	61.91	73.51	46.68	25.49 21.13	67.53	56.17	58.25	T 23
51.53	54.50	59.66	47.26	96.25	48.78	58.77	18.13 6.22	54.78	25.58	T 113
48.90	66.60	54.58	55.52	76.34	56.63	49.15	50.87	11.84 6.22	57.99	T 24
43.49	50.55	47.76	46.81	52.11	46.07	50.64	21.04	50.15	15.66 13.19	T 117

The upper and under orthogonal partitions indicate ear weight and shelled corn weight, respectively.

Table 2. Estimates of genetic constants of 10 lines and their 45 crosses.

Genetic constants	ear w.	shelled c.	Genetic constants	ear w.	shelled c.
	22.12	17.58	h_{23}	33.73	28.95
l_1	− 1.19	− 0.24	h_{24}	18.32	15.98
l_2	14.63	13.13	h_{25}	39.86	36.14
l_3	6.25	5.30	h_{26}	39.08	36.00
l_4	7.36	4.62	h_{27}	40.54	35.99
l_5	1.67	0.66	h_{28}	27.75	24.15
l_6	−11.34	− 9.02	h_{29}	39.38	37.04
l_7	3.37	3.55	h_{210}	27.56	24.86
l_8	− 3.99	− 2.83	h_{34}	36.76	27.60
l_9	−10.28	−11.36	h_{35}	44.28	39.57
l_{10}	− 6.36	− 4.39	h_{36}	54.18	47.80
			h_{37}	37.88	33.43
$\bar{h}$	41.21	37.02	h_{38}	46.05	40.57
h_1	− 0.69	− 1.54	h_{39}	44.54	40.03
h_2	−16.23	−14.63	h_{310}	34.43	29.72
h_3	− 4.12	− 4.74	h_{45}	46.26	40.92
h_4	− 3.55	− 2.67	h_{46}	55.16	48.82
h_5	7.29	7.86	h_{47}	45.90	40.98
h_6	12.40	10.23	h_{48}	40.69	35.75
h_7	− 1.24	− 1.04	h_{49}	55.99	52.45
h_8	− 0.31	− 0.98	h_{410}	36.92	32.86
h_9	10.59	12.28	h_{56}	54.93	48.42
h_{10}	− 4.17	− 4.75	h_{57}	56.64	53.62
			h_{58}	57.17	50.57
h_{12}	32.06	28.48	h_{59}	58.88	55.11
h_{13}	33.15	29.22	h_{510}	39.91	36.40
h_{14}	39.74	35.39	h_{67}	34.24	31.84
h_{15}	46.95	42.34	h_{68}	42.16	36.54
h_{16}	52.66	46.13	h_{69}	53.94	48.94
h_{17}	40.49	36.01	h_{610}	39.44	35.20
h_{18}	40.70	35.21	h_{78}	45.72	40.55
h_{19}	40.23	37.12	h_{79}	37.51	35.47
h_{110}	32.77	30.22	h_{710}	37.68	37.68
			h_{89}	39.80	39.80

Table 2. (continued)

Genetic constants	ear w.	shelled c.	Genetic constants	ear w.	shelled c.
h_{810}	8.15	7.33	s_{38}	9.27	9.27
h_{910}	44.24	40.44	s_{39}	− 3.14	−4. 53
			s_{310}	1.51	2.19
s_{12}	7.77	7.63	s_{45}	1.31	−12.29
s_{13}	− 2.30	− 1.52	s_{46}	5.10	3.24
s_{14}	2.77	2.58	s_{47}	9.48	7.67
s_{15}	− 0.74	− 1.00	s_{48}	3.34	2.38
s_{16}	− 0.26	0.42	s_{49}	7.74	5.83
s_{17}	1.21	1.57	s_{410}	3.43	3.26
s_{18}	0.49	1.71	s_{56}	− 5.97	− 6.96
s_{19}	−10.88	−10.64	s_{57}	9.98	9.38
s_{110}	− 3.68	− 0.49	s_{58}	8.90	6.17
s_{23}	12.87	11.30	s_{59}	− 0.29	− 1.15
s_{24}	− 3.11	− 4.13	s_{510}	− 4.42	− 4.23
s_{25}	2.47	5.89	s_{67}	−18.14	− 6.09
s_{26}	1.70	3.20	s_{68}	−12.14	− 9.73
s_{27}	17.80	14.64	s_{69}	−10.26	−10.59
s_{28}	3.08	2.74	s_{610}	−10.00	− 7.30
s_{29}	4.81	2.38	s_{78}	6.12	5.53
s_{210}	11.21	6.75	s_{79}	−13.05	−12.77
s_{34}	3.22	− 2.01	s_{710}	1.88	1.80
s_{35}	− 0.10	0.57	s_{89}	−11.69	− 5.23
s_{36}	5.69	5.29	s_{810}	−28.48	−23.96
s_{37}	1.03	2.74	s_{910}	− 3.39	− 4.16

underlined numbers showed the highly favorable non-additive (specific) effects in special crosses.

Table 1, the F_1 showed highly heterosis effects resulted by the combinations between parents which are quite different in genotype, in yields of ear weight and shelled corn. In fact, the average heterosis ($\bar{h}$) were 41.21 and 37.02, respectively. And the heterosis effect were contributed not only actions of genes in arithmetic way, but by actions in non-additive appeared in some combinations of special parents, such as s_{23} and s_{27}, which were determined as 12.87, 11.30 and 17.80, 14.64, collectively. Table 3 also showed the significance of specific effect. Actually, the 2nd line, i. e., *N* 56 showed fairly high specific effects ($s_{2\cdot}$) when it was crossed with other lines

Table 3. Analysis of variances of 10 inbred lines and their 45 crosses in a diallel set.

Source	d.f.	M.S. ear w.	M.S. shelled c.
entries	54		
lines (l_k)	9	139.85**	106.62**
lines vs crosses ($\bar{h}$)	1	28016.06**	22522.73**
crosses ($h_{kk'}$)	44	191.57**	150.19**
G.C.A.)g_k)	9	490.55**	353.11*
S.C.A. ($s_{kk'}$)	35	114.68*	98.01**
errors	54	59.10	46.29

** significant at 1% * significant at 5%

Table 4. Predicted yields of Syn. 2 derived from 2 to 10 lines.

Ear weight kg/a	FORMULA (IV) I	FORMULA (IV) II	FORMULA (IV) III	WRIGHT'S method I	WRIGHT'S method II	WRIGHT'S method III
C^r_{12}	44.87	42.27	38.28	44.89	43.77	34.55
C^r_{123}	50.67	51.27	43.40	50.70	51.93	41.68
C^r_{1234}	53.10	56.66	42.54	53.12	58.88	41.66
C^r_{12345}	57.55	60.79	47.00	57.00	61.83	46.41
C^r_{123456}	59.80	60.28	53.08	59.42	61.11	52.40
$C^r_{1234567}$	61.11	$\underline{60.77}$	54.46	60.84	$\underline{61.38}$	54.50
$C^r_{12345678}$	$\underline{61.19}$	60.59	56.83	58.45	58.45	56.46
$C^r_{123456789}$	61.17	58.40	53.92	$\underline{61.35}$	58.76	57.62
$C^r_{12345678910}$	59.21	59.00	$\underline{59.16}$	59.20	59.21	$\underline{59.21}$
Shelled corn kg/a						
C^r_{12}	38.27	38.63	31.86	38.27	41.27	31.96
C^r_{123}	42.90	41.57	37.00	42.92	41.38	37.05
C^r_{1234}	43.98	42.06	37.89	43.99	47.08	34.45
C^r_{12345}	44.36	50.42	40.69	48.37	51.42	40.58
C^r_{123456}	50.03	50.92	45.82	50.70	52.07	44.22
$C^r_{1234567}$	51.69	$\underline{52.59}$	47.97	52.21	$\underline{52.48}$	48.39
$C^r_{12345678}$	51.91	49.54	49.57	52.39	50.16	50.56
$C^r_{123456789}$	$\underline{52.70}$	50.59	50.48	$\underline{52.57}$	50.88	$\underline{51.10}$
$C^r_{12345678910}$	50.81	50.76	$\underline{57.73}$	50.89	50.87	50.67

underlined numbers showed the highest performances of synthetic variety corresponding to the optimum number of parents which should be used.

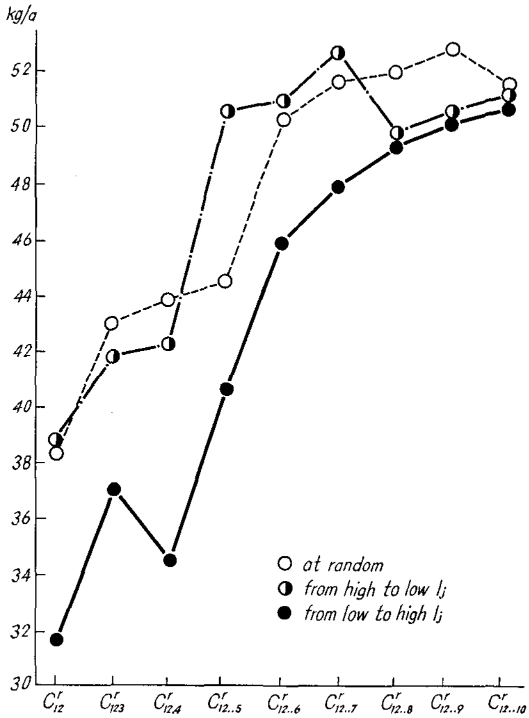

Fig. 1. Shelled corn yield of Syn 2 predicted by Formula IV.

(Table 2); furthermore *N* 56 also owned the highest value of $I_2=14.63$; *N* 56 must be selected firstly as favorable parental line of breeding a synthetic variety of high yield in maize.

Predicted yield of the second generation or SYN. 2 was given in Table 4. The results of three cases of mating (I: at random; II: parents were arranged from high to low l_j; III: parents were arranged from low to high l_j), were computed by Wright's method and the formula (IV). From the Table 4, we understood that the suitable number of inbred lines to develop a synthetic variety of maize was varied from 7 to 10. By arranging the parents in order of high l_j to low l_j in mating system, we could minimize the number of parents to 7 as shown in Table 4 and Figure 1, 2, respectively.

Acknowledgement

The authors are grateful for the valuable cooperations of MR. KANEKO, MR. ABE, and MR. INOUE of the Laboratory of Corn Breeding, Hokkaido

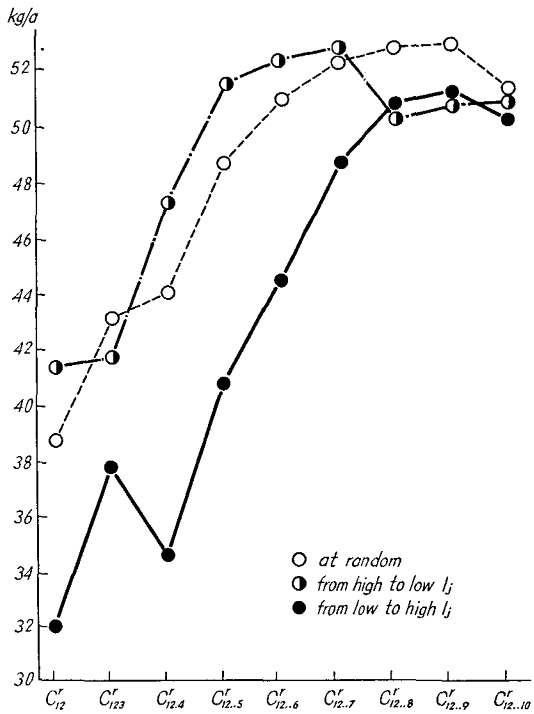

Fig. 2. Shelled corn yield of Syn 2 predicted by Wright's formula.

National Agriculture Experiment Station, in writing this paper. Hearty thanks are also due to DR. TSUDA, Assistant Professor of Industrial Crops Laboratory, for his very kindness of reading the manusript and giving helpful criticisms.

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